

The University of Chicago

RADIATION FROM CANAL RAY IMPACT

A DISSERTATION SUBMITTED TO THE
FACULTY OF THE DIVISION OF THE PHYS-
ICAL SCIENCES IN CANDIDACY FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICS

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FRANK LOUIS VERWIEBE

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Radiation From Canal Ray Impact

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Hydrogen canal rays accelerated in fields up to 40 kv were allowed to impinge on a metal target and the beam of particles and radiation emitted from the target were investigated. Pinhole images of the focal spot were obtained on Schumann plates and plates coated with molybdenum trioxide. The presence of atomic hydrogen was shown by a characteristic light blue color produced on molybdenum trioxide plates. By means of a deflecting magnetic field it was found that the beam from the target consisted mainly of neutral particles (or of radiation) but contained a

smaller number of protons whose velocity was practically equal to that of the protons incident on the target. The neutral particles by virtue of their ability to affect a photographic plate could suggest the presence of electromagnetic radiation. A grating was used to detect such radiation. Radiation of wave-length 1216A was excited in the residual gas by the canal ray beam when the pressure was as low as 10^{-4} mm of Hg. Any characteristic radiation from the target excited by canal ray impact is too small to be measured.

THE excitation of radiation by the impact of rapidly moving positive particles on metals has formed the subject of several investigations. On the one hand, there has been the search for a penetrating radiation similar to x-rays that might be expected from the impact of protons. Of such a nature were the experiment of Barton¹ in 1930, and the recent experiments of Cockcroft and Walton.² They attempted to determine whether gamma-radiation or x-radiation of sufficiently short wave-length to pass through a thin mica window was produced by the impact of positive ions on matter with accelerating potentials up to 700 kv. These workers report that, if any such radiation is produced, its intensity was inappreciable. According to Cockcroft and Walton its intensity was certainly not greater than 10^{-6} of the intensity of the continuous x-radiation which would have been produced by an electron stream of the same energy.

On the other hand, there is undoubtedly excited an easily observable nonpenetrating radiation that can penetrate only the thinnest celluloid windows. This radiation has been studied by Thomson,³ Wien,⁴ Gerthsen,⁵ and others, but the experiments have not as yet

conclusively decided whether the effects observed are predominantly due to soft x-rays excited in the target, or to scattered positive or neutral atoms, and furthermore, no determinations have been made of the wave-length of the radiation, if electromagnetic radiation is excited in appreciable intensity.

J. J. Thomson³ in his 1914 paper concluded that he had found an electromagnetic radiation excited by the impact of canal rays on a target. He seems not to have considered, however, that neutral particles would pass through a deflecting field and affect a photographic plate. In 1926 Thomson⁶ studied this radiation by means of the photoelectric effect in a second chamber separated by a celluloid window. Radiation seemed to come from the target but also from the gas in the discharge tube when the target was removed.

In 1927 Wien⁴ reported an unexpected fogging of Schumann plates when they were in a gas at a pressure of 0.001 mm of Hg through which canal rays were passing. This occurred even when they were shielded from any direct action from the rays and the metal struck by the rays. A deflecting magnetic field or electrostatic field which would eliminate secondary electrons produced no change. While Wien did not attempt a definite explanation, he did suggest that, rather than electromagnetic radiation, the cause might be a chemical action of atomic hydrogen and oxygen on the silver of the Schumann plates. Ordinary plates protected by the layer of

¹ Barton, J. Frank. Inst. **1**, 209 (1930).

² Cockcroft and Walton, Proc. Roy. Soc. **A136**, 619 (1932).

³ J. J. Thomson, Phil. Mag. **28**, 620 (1914).

⁴ Wien, Ann. d. Physik **83**, 1, 19 (1927).

⁵ Gerthsen, Ann. d. Physik **85**, 881 (1928).

gelatine did not show the fogging. The degree of fogging increased with increasing pressure and was less with nitrogen in the tube than with hydrogen or oxygen.

In 1928 Gerthsen⁵ investigated the radiation caused by the impact of canal rays on metals. He used the photoelectric effect and an experimental arrangement which allowed him to repeat all the observations reported by Thomson⁶ in 1926. He concluded that the beam of particles reflected from the target consisted mainly of neutral particles of high velocity and that they could produce all the effects ascribed to electromagnetic radiation, *viz.*, secondary electron emission, ionization of gases, and the blackening of a photographic plate. He found, furthermore, that the absorption of these reflected beams in thin celluloid windows was of the same order of magnitude as the absorption of soft x-rays. To get a separation, therefore, of particles and electromagnetic radiation, an effect purely optical in its nature would have to be utilized, such as reflection from a mirror or diffraction by a grating. Gerthsen accordingly attempted to use such an optical effect and set up sputtered concave mirrors to focus any electromagnetic radiation coming from the target. He did find a slight increase of photoelectric current for the proper angular setting of the mirrors but was unable to decide whether the radiation observed was due to radiation from the beam or to characteristic radiation excited in the target.

The present experiment was undertaken to attempt to determine by means of a diffraction grating whether soft electromagnetic radiation is excited by the impact of canal rays on a target and its wave-length, if any is excited. It was also hoped that the experiment would aid in deciding whether the effects described by other observers were due to electromagnetic radiation or to reflected neutral particles.

APPARATUS

The experimental arrangement used is sketched diagrammatically in Fig. 1. A hydrogen discharge tube (120 cm×4 cm) was mounted over a slit system leading to a photographic chamber. An electrically heated palladium tube was joined to

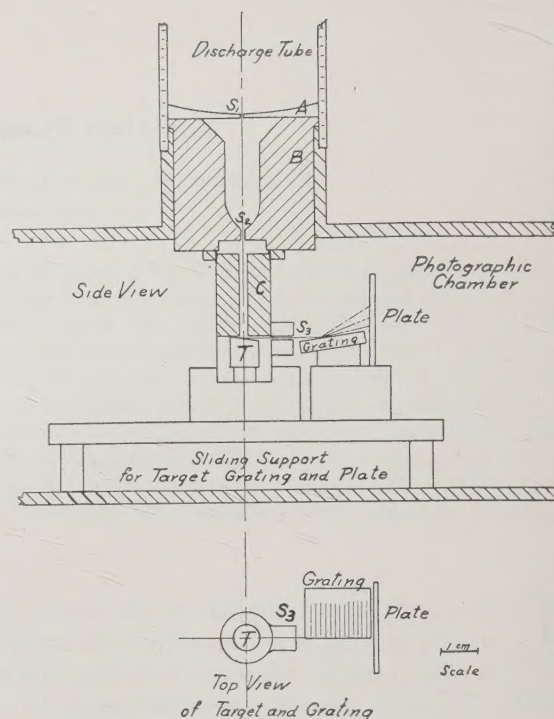


FIG. 1. Experimental arrangement for diffraction patterns.

the system to control the influx of hydrogen from a reservoir, and a transformer in conjunction with a kenotron provided the potential difference. The cathode consists of the cylindrical block *B*, on top of which is a slightly concave piece of aluminum *A*. The slits *S*₁ and *S*₂ are each a fine pinhole punched in foil. With this arrangement it was possible by means of two diffusion pumps to maintain the proper discharge pressure in the tube and at the same time keep the pressure in the photographic chamber below 10⁻⁴ mm of Hg. Below the block *B* is a carriage, arranged to slide out for loading purposes, on which are mounted the target *T*, the slit *S*₃, the grating, and the plateholder. The block *C* was inserted in some experiments to prevent radiation from the incident beam reaching the plate. The upper edge of the target is in line with the adjustable, rectangular slit *S*₃, through which the rays from the target pass to the grating and thence to the sensitive plate. The top view of the target and grating shows the mounting of the latter which permits part of the emergent beam to fall directly on the sensitive plate. The grating was ruled with 600 lines to the millimeter.

⁶ J. J. Thomson, *Phil. Mag.* 2, 674 (1926).

To detect radiation and fast moving particles Schumann plates were used. In addition, pieces of glass smoked with molybdenum trioxide vapor were also utilized. These have a fine whitish surface which is insensitive to radiation but which becomes blue when bombarded by atomic hydrogen.

In some of the tests, moving charged particles were deflected by a magnetic field applied normally to the direction of the beam coming from the target and parallel to the direction of the slit S_3 as shown in the figure.

EXPERIMENTAL PROCEDURE

The experimental procedure was as follows. The voltage across the discharge tube was maintained between 35 and 40 kv. The amount of hydrogen flowing through the tube was such that a pressure of approximately 0.02 mm of Hg was established in the tube, and a beam of canal rays about 1 mm in diameter was visible in front of the cathode.

With canal rays impinging on the target a study was made of the composite beam of radiation emerging from the target through the slit S_3 . In studying the nature and characteristics of the corpuscular beam as well as the electromagnetic radiation coming from the target, the following experiments were carried out.

1. Pinhole images

Pinhole images to determine the position and area of the source of the radiation were taken with the arrangement shown in Fig. 2. The block, C , here drawn with dotted lines, was removed. A pinhole punched in a piece of foil was opposite the target. The photographic plate was placed so that the pinhole was midway between the point of impact on the target and the photographic plate in order that full size images would be obtained. Fig. 4a is a drawing of a typical Schumann plate photograph obtained in this manner. It shows an intense beam coming from the spot on the target struck by canal rays. The elliptical shape is a projection of the circular focal spot on the target. There is also visible on the plate a fainter image of a portion of the canal ray beam itself. When a molybdenum trioxide plate was exposed in this manner this faint vertical line did not appear,

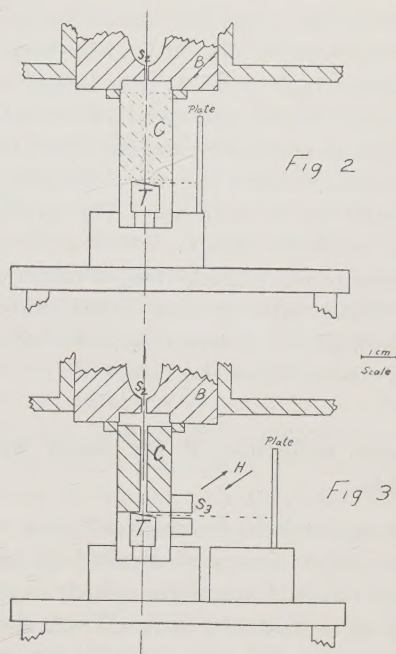


FIG. 2. Arrangement for pinhole images.
FIG. 3. Arrangement with deflecting magnetic field.

indicating that probably electromagnetic radiation was the cause of this faint line image.

When the block C was inserted, this radiation coming from the canal ray beam itself was prevented from reaching the sensitive plate. Fig. 4b represents photographs obtained with this arrangement. Both Schumann plates and molybdenum trioxide plates were exposed and both show the same type of image, the latter

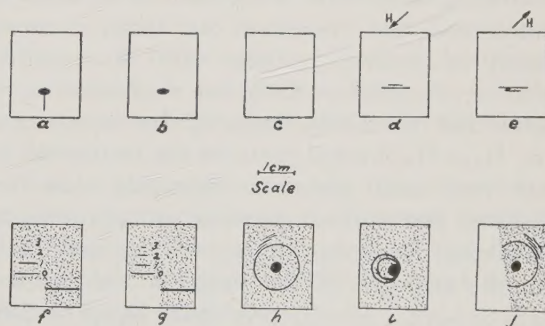


FIG. 4a. Pinhole image of beam and target. b. Pinhole image of focal spot only. c. Rays from target through slit. d. Magnetic deflection of rays from target. e. Image with magnetic field reversed. f. Diffraction pattern of rays from canal ray impact. g. Diffraction pattern from ultraviolet spark. h. Rings due to rays reflected from brass opening. i. Rings from displaced opening. j. Plate partly covered with cellophane.

plates, however, requiring considerably longer time of exposure to obtain a clear image. The characteristic blue color of the images on the molybdenum trioxide plates shows conclusively that the beam coming from the target contains atomic hydrogen, since the molybdenum trioxide is not sensitive to radiation. The general appearance of these images bears a very close resemblance to the pinhole images taken with an ordinary x-ray tube. It was found that a thin piece of cellophane completely absorbed all the radiation coming from the target.

2. Magnetic deflection of the beam from the target

The beam of particles and radiation coming from the target was next studied to see if it contained charged particles which would be deflected by a magnetic field. When the beam was allowed to fall on a plate through the rectangular slit, S_3 , as shown in Fig. 3, a horizontal image of the slit was obtained as indicated by Fig. 4c. As before, the molybdenum trioxide plates showed the same images as the Schumann plates.

When a magnetic field of a few hundred gauss was applied normal to the direction of the beam, a deflected image appeared as indicated by Figs. 4d and 4e. The molybdenum trioxide did not show the deflected image probably because of lack of intensity in the deflected beam. The Schumann plate photographs reveal several interesting facts. First of all, most of the beam is undeflected and therefore the beam consists mainly of neutral particles with the possible addition of radiation. Only one displaced line is visible and this is very probably due to protons. Any H_2 or H_3 charged particles can be present in only very small amounts. Assuming that the displaced line is due to protons, an approximate calculation from the amount of the deflection and the strength of the magnetic field shows them to have a velocity practically equal to that of the protons incident on the target. This experimental arrangement is practically that of Thomson's 1914 experiment. Instead of a magnetic field he used an electrostatic field, which deflected the charged particles and allowed the neutral particles to reach the photographic plate.

3. Grating diffraction patterns

The undeflected images on the photographic plates as shown by Figs. 4d and 4e might be due to radiation as well as to neutral particles coming from the target. In order to determine if any radiation was also present, a diffraction grating was interposed between the slit S_3 and the photographic plate, as shown in Fig. 1. Canal rays were allowed to fall on the various targets, brass, calcite, and magnesium, and exposures were taken to obtain the spectrum of any possible electromagnetic radiation. Fig. 4f is a drawing of a typical Schumann plate photograph obtained in this manner. The line in the lower right-hand corner of the plate is due to the unreflected beam coming from that part of the slit which was not covered by the grating, as indicated in the top-view shown in Fig. 1. The clear rectangle in the lower left-hand corner is the shadow cast by the grating. Above the upper edge of the grating shadow there can be seen the directly reflected beam, the zero order of diffraction, and above it several higher orders of diffraction images. Except for the portion of the plate protected by the grating, there is a general fogging over the plate which makes the original unsuitable for reproduction. The line in the lower right-hand corner, due to the unreflected beam, is much more intense than any of the reflected images, the latter requiring as much as six to ten hours' exposure for the higher orders, whereas the former is visible after a few minutes exposure and often showed reversal for the longer exposures. Furthermore, the general fogging was visible on exposures which were not long enough to bring out the diffraction pattern. This indicates that the energy emerging from the slit is predominantly in the form of particles and that these particles can blacken the photographic plate.

Since the distance between the point of incidence on the grating and the plate was only a little over 1 cm, the accuracy of the wavelength determination could not be very great. As computed, however, the value of the wavelength of this radiation was found to agree within the limit of the accuracy of the measurements with that of the first Lyman line, 1216Å. The shortest wave-length for which a diffraction pattern could have been distinguished is about

100Å. No wave-lengths between this value and 1216Å were found. This radiation may have been present in Thomson's experiments and Gerthsen suspected his results to be due partly, at least, to radiation of this wave-length. The molybdenum trioxide plate in this position showed only the unreflected image on the portion not covered by the grating.

This electromagnetic radiation comes from the gas just in front of the inclined target and these experiments show no reason to assume that an electromagnetic radiation is excited in the target itself.

4. Diffraction patterns from an ultraviolet spark

In order to make certain that the experimental arrangement was capable of indicating the presence of wave-lengths shorter than 1216Å, an ultraviolet spark was placed opposite the grating. An intermittent discharge from a condenser connected in parallel across a gap of about 1 mm was allowed to pass between the two carbon electrodes mounted in Bakelite. The pressure in the photographic chamber was kept below 10^{-4} mm of Hg. About 50 kv were applied to the condenser so that a very intense spark was obtained. Fig. 4g is a drawing of the diffraction pattern obtained. The value of the strongest line obtained with the particular angle of grating used was found to lie between 500 and 600Å. Precision spectrographs show two fairly strong lines at 500 and 538Å, respectively, due to C III.

5. Incidental effects

In the preliminary steps of getting the two upper slits and the target into proper alignment, exposures were made with plates in the position of the target, *T*, as shown in Fig. 1. Sketches of the photographs obtained in this manner are shown in Figs. 4h and 4i. They show a large central spot, at least one fairly prominent ring around it, and several fainter rings of larger diameters. Exactly the same patterns were

obtained with molybdenum trioxide plates as with Schumann plates. The diameter of the rings was found to be independent of wide variations in voltage, pressure, and the size of the pinhole at the bottom of slit *S*₂. The first ring in Fig. 4h was traced geometrically to the upper edge of the slit *S*₂. When a smaller tube was placed above the pinhole the pattern shown by Fig. 4i was obtained, and, as before, the first ring around the central spot could be traced to the upper edge of the tube. The larger rings in both plates seem to be due to scorings on the inner surfaces of the cylindrical chambers above the slit *S*₂. Since these rings appear also on the molybdenum trioxide plates they must be caused by atomic hydrogen. They may be due to a charging up of the metal surface and a consequent deflection of charged particles from the discharge tube. This deflection may be through a large angle when the charged particles pass close to the scoring in the metal surfaces, so that the rays can pass through the slit *S*₂, and cause a circular trace on the photographic plate.

Reference was made at the beginning of this article to the anomalous fogging observed by Wien. In the present experiment all the plates show some fogging and this seems to be the result of scattered charged and uncharged particles. Both Schumann plates and molybdenum trioxide plates show the same effect. Fig. 4j is a drawing of a Schumann plate put in the position of the target *T*, as shown in Fig. 1, with about one-half of the plate covered by a thin piece of cellophane placed 1 mm above it. The part of the plate protected by the cellophane is completely clear. The general blackening is caused predominantly by charged or uncharged ions, as in these experiments we have seen that both will blacken a Schumann plate.

The writer wishes to take this occasion to express his indebtedness to Professor Dempster for his suggestion of the problem and for his advice and helpful criticism throughout the course of the experiment.



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